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Determination of Skyline Load Capability with a Programable Pocket Calculator

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Reference Abstract

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For planning purposes, logging engineers need tools and methods to determine the load-carrying capability of skyline cable systems. Both computerized and hand computation methods are available for these determinations; however, no approach has been reported that could be programed onto the pocket-size computers available. This paper presents a method that will determine the load capability of a running or standing skyline on a programable pocket-size calculator.

KEYWORDS: Skyline logging, computation, computer programs.

RESEARCH SUMMARY

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The trend toward more intensive advance planning of logging activities has definitely been established in recent years, particularly for cable logging operations. Logging specialists and forest engineers now commonly investigate the relationship between cable tensions, ground profile shapes, anchoring geometries, and anticipated log loads before actual field operations. The primary objective is to establish the workability of a proposed operation before actual logging begins.

The nature of this advance planning is inherently computational. For skylines, the relationship between tensions, loads, and geometries can be determined; but a great deal of numerical manipulation is involved. To make the exercise most practical, a computer is required.

The degree of practicability associated with performing the computations necessary for planning skyline logging depends on the availability and cost of the computer. The geographically dispersed nature of forest operations makes the large central computer impractical for most situations because of inaccessibility or cost. The introduction of inexpensive,

pocket-size, programable calculators has, however, changed this situation. These computers are readily available and can perform many of the calculations required for advance planning.

This paper presents the mathematical expressions that make possible determination of the relationship between tensions, geometry, and loads for running and standing skylines. The expressions are condensed to a degree that allow them to be programed on a pocket-size calculator. Approximations are entailed; however, the error associated with them was negligible and is discussed. The derivations presented have been the basis for several computer programs now available on pocket-size calculators.

Introduction

An important step in the process of examining the feasibility of a proposed skyline logging operation is the determination of the load-carrying capability of the skyline equipment. This capability is a function of the equipment size, the anchoring arrangement, and the amount of deflection allowed by the terrain over which the skyline is intended to operate. Determination of the load-carrying capability presents a computational problem to which considerable attention has been devoted, with the result that logging engineers have available several methods for solution. These methods fall into the general categories of (a) handbook methods (*6, 7*) which use a "chain-and-board" physical analogy and a tabulated set of cable tension and geometry characteristics to determine load-carrying capabilities, and (b) computer methods (*1, 4, 5*) which use a mathematical approach.

This paper presents another computer method for determination of skyline capabilities. The approach is conceptually the same as the computer solutions reported previously; however, whereas the early methods required large or at least desk-top computers, this solution can be accomplished on a programable pocket calculator. Some accuracy of the mathematical description has had to be sacrificed; however, comparisons with other available methods have shown the accuracy of the calculator results to be adequate for a wide range of practical situations.

The purpose of this paper is to show the mathematics and assumptions which were necessary to put the solution for skyline load-carrying capability on a hand-held computer. A Hewlett-Packard 65[1/] was used; this computer is capable of executing 100 programed steps and has 9 addressable storage registers. Two programs have been prepared and are discussed in this paper: (a) a solution for the load-carrying capability of a standing skyline shown in figure 1 and (b) a solution for the load-carrying capability of a running skyline shown in figure 2.

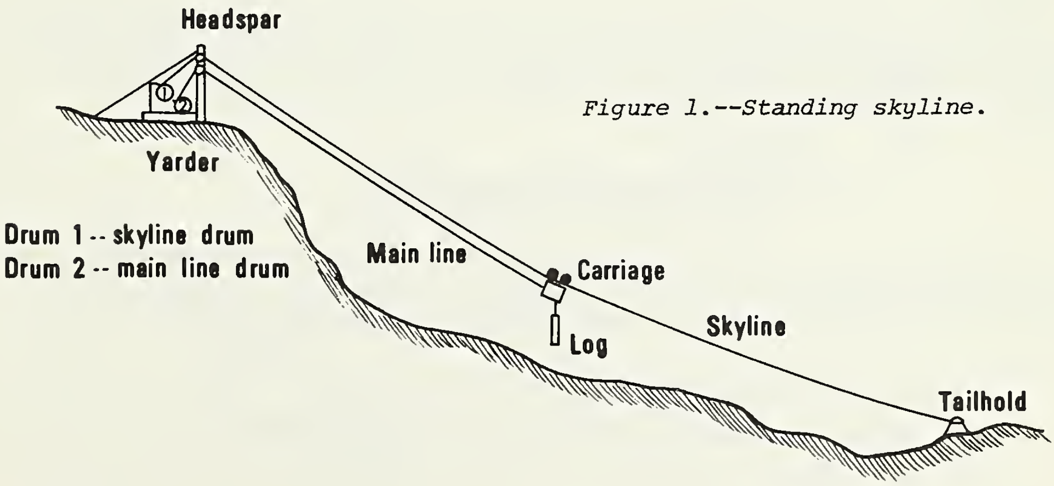

Figure 1.--Standing skyline.

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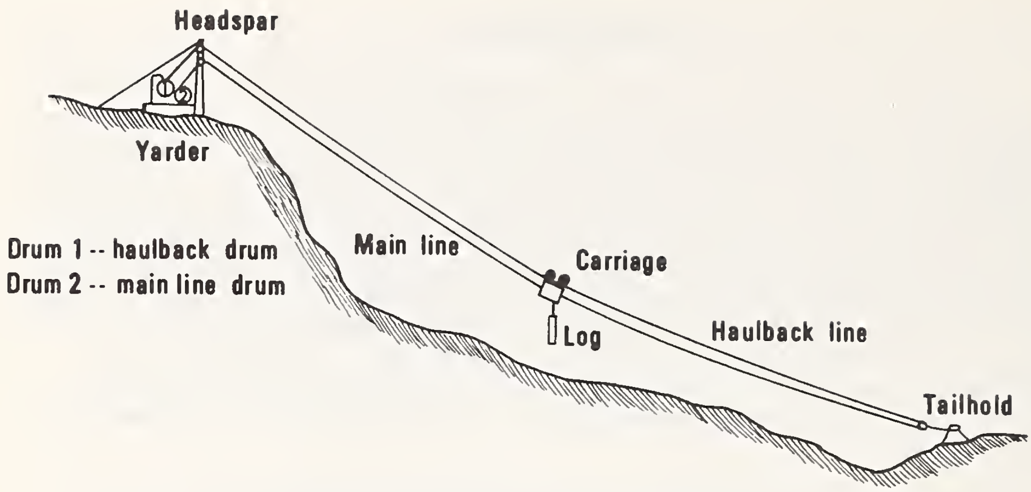

Figure 2.--Running skyline.

BACKGROUND

Analysis of the relationship between tensions, loads, deflections, and line lengths for a skyline system will yield mathematical equations in terms of the hyperbolic functions which describe a catenary curve. Solution of equations will relate the physical variables of the system. However, the determination of these solutions is not trivial; and if computers are to be used, a large computing facility is required. If one wishes to avoid the large computers and would prefer to use a desk-top computer or the programable pocket computer, then the complexity of the mathematical description of the skyline systems must be simplified. This is accomplished by introducting assumptions which simplify but limit the applicability of the results.

This paper discusses the analysis of two skyline systems. The assumptions and subsequent limitations are implicit in this discussion and should be understood by anyone who intends to apply the results of this solution.

The Problem Description

In this paper, mathematical equations are derived to express the gross payload capability, W_G, of a standing or running skyline as a function of the cable systems geometry which is described by

L, the span between anchor points,

h, the elevation difference between anchor points,

d, the horizontal distance from the left anchor to the carriage,

and y, the elevation difference from the left anchor point measured positive down to the point where the carriage rests on the skyline (or haulback);

and the line weights related to

ω_1, the weight per unit length of the skyline

and ω_3, the weight per unit length of the main line, or for the running skyline, the main line-operating line combination;

and T_A, the operating tension of the systems which are given to exist at the left anchor in the skyline of the standing configuration and in the haulback of the running skyline system.

In the computer programs based on these mathematical descriptions, the specified values are then L, h, d, y, ω_1, ω_3, and T_A; and the expected result is W_G.

Mathematical Description

Carson and Mann (*2, 3*) discussed the mathematical description necessary to determine load-carrying capability for the standing and running skylines, respectively. Recognizing the difficulties associated with the catenary description of these cable systems, the authors discussed an approximate approach as the force balance formulation. This approach will be used here also.

TENSIONS

Consider the free body diagrams of the standing and running skyline cable configurations as depicted in figures 3 and 4, respectively. For

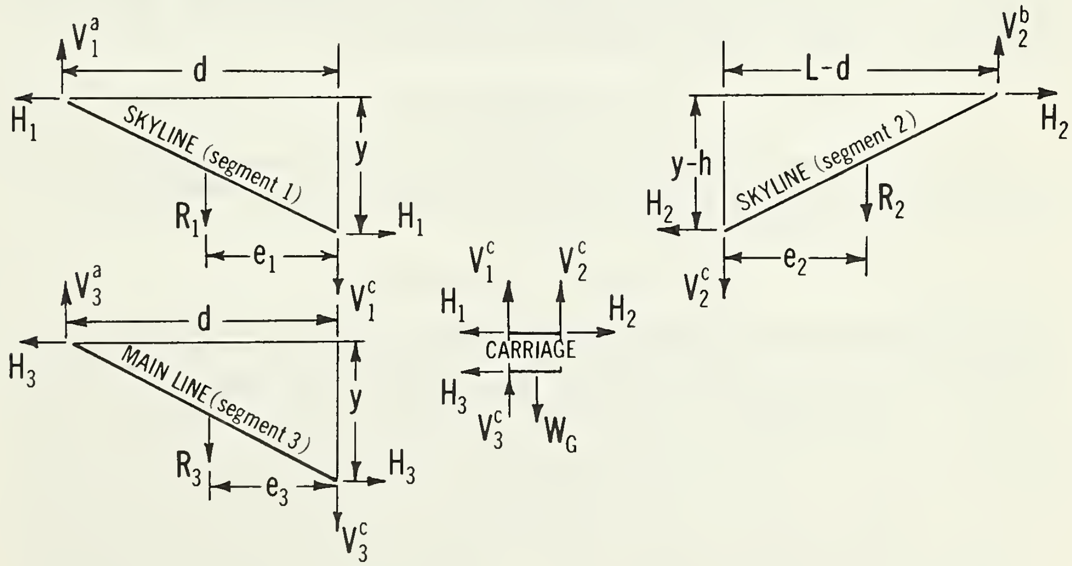

Figure 3.--Free body diagram for standing skyline.

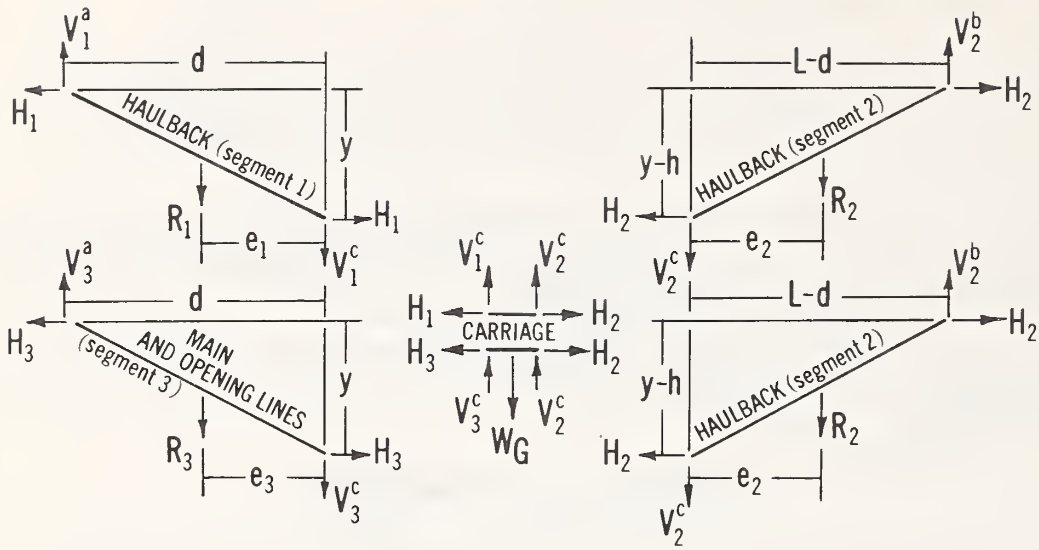

Figure 4.--Free body diagram for running skyline.

both these systems, one can express the horizontal component of tension in line segment 2, H_2, in terms of the known geometric quantities L, h, d, and y; the skyline or haulback tension, T_A, and the line weight per unit length, ω_1. This is accomplished by first using a catenary relationship which states that the tension in the skyline (or haulback) at the carriage is equal to the tension at the headspar minus the product $\omega_1 y$. This and the fact that the tension in this support line is the same on each side of the carriage support sheave provide the expression

$$\left(T_A-\omega_1 y\right)^2=\left(V_2^c\right)^2+\left(H_2\right)^2. \tag{1}$$

The vertical and horizontal components in this expression are related to the line weight and shape of the cable segment. The relationship is revealed in the moment balance

$$V_2^c(L-d)=H_2(y-h)-R_2\left(L-d-e_2\right). \tag{2}$$

Combining these, one gets the quadratic equation

$$H_2{}^2\left(1+t_3^2\right)-2H_2R_2t_3\ \left(1-t_4\right)+R_2{}^2\left(1-t_4\right)^2-\left(T_A-\omega_1 y\right)^2=0; \tag{3}$$

where $$t_3=\frac{y-h}{L-d}\ ,$$

and $$t_4=\frac{e_2}{L-d}\ .$$

V and H are force components in the lines; R is the force component resulting from line weight, and e indicates the moment arm associated with this force. All these terms are defined as shown in figures 3 and 4.

LINE WEIGHTS AND MOMENT ARMS

An assumption which simplifies the mathematics of this description substantially involves the line weights and moment arms of the line segments which depend on the physical shape of each segment, a catenary in reality, and the line weight per unit length:

(a) the line weight is equal approximately to the product of the weight per unit length and the chord length. For the segments in these systems, the weights would be expressed as

$$R_1=\omega_1\left(d^2+y^2\right)^{1/2}; \tag{4}$$

$$R_2=\omega_1\left(\left(L-d\right)^2+\left(y-h\right)^2\right)^{1/2}; \tag{5}$$

and

$$R_3=\omega_3\left(d^2+y^2\right)^{1/2}. \tag{6}$$

In keeping with this assumption, the second simplification is to assume:

(b) the moment arm for the weight of each segment is at the middle of its span. This provides

$$e_1=e_3=1/2d; \tag{7}$$

and

$$e_2=1/2\left(L-d\right). \tag{8}$$

The effect of these assumptions on accuracy of the solution for the running skyline was discussed by Carson and Mann (*3*). The results of a description with these assumptions, such as the one used here, approximate the catenary solution to within a fraction of a percent when the lines are taut. Cables with low tensions will sag and adopt a catenary shape whose length is substantially longer than the chord length. In such cases error will result, the magnitude being proportional to the amount of sag; however, in most cases the cables will be stressed to a maximum working value to carry the largest loads possible. With these conditions, the results of the present analysis are accurate. Nevertheless, those who use these results should keep this limitation in mind.

GROSS PAYLOAD

With the simplified line weight and moment arm expressions of the previous section, the quadratic solution for H_2 can be reduced to:

$$H_2=\frac{\omega_1(L-d)}{2\left(1+t_3{}^2\right)^{1/2}}\left\{t_3+\left[4\left(\frac{T_A}{\omega_1(L-d)}-\frac{y}{L-d}\right)^2-1\right]^{1/2}\right\}. \tag{9}$$

This holds for both standing and running skyline configurations.

The load-carrying capability of each configuration can be related to this component of tension by noting the vertical force balance at the carriage which becomes

$$W_G=V_1{}^c+V_2{}^c+V_3{}^c \tag{10}$$

for the standing skyline and

$$W_G=V_1{}^c+2V_2{}^c+V_3{}^c \tag{11}$$

for the running skyline. The vertical components of tension can be derived from moment balances:

$$V_1{}^c=H_1t_1-1/2R_1; \tag{12}$$

$$V_2{}^c=H_2t_3-1/2R_2; \tag{13}$$

and

$$V_3{}^c=H_3t_1-1/2R_3; \tag{14}$$

where $t_1=y/d$ is introduced here. Substitution of these for equations (10) and (11), respectively, give

$$W_G=\left(H_1+H_3\right)t_1+H_2t_3-1/2\left(R_1+R_2+R_3\right), \tag{15}$$

and

$$W_G=\left(H_1+H_3\right)t_1+2H_2t_3-1/2\left(R_1+2R_2+R_3\right). \tag{16}$$

At this point the horizontal force balance is introduced to provide the relationships

$$H_2=H_1+H_3 \tag{17}$$

for the standing skyline and

$$2H_2=H_1+H_3 \tag{18}$$

for the running skyline configuration. Substitution of these provides the

final expressions for the payload; namely,

$$W_G=H_2\left(t_1+t_3\right)-1/2\left(R_1+R_2+R_3\right) \tag{19}$$

for the standing skyline and

$$W_G=2H_2\left(t_1+t_3\right)-1/2\left(R_1+2R_2+R_3\right) \tag{20}$$

for the running skyline configuration. These equations and the computed value of H_2 provide the load-carrying capability as a function of the geometry implied by L, h, d, and y; the line weights derived from ω_1 and ω_3; and the working tension of the skyline (or haulback) specified as T_A.

MAIN LINE TENSION

In both skyline configurations, an amount of main line tension is required to maintain the carriage location. The magnitude can be related to the horizontal component of tension, H_3, which is related to the horizontal components, H_1, and H_2, as expressed in the previous section. As for H_1, a quadratic solution similar to that used for H_2 is available in the form

$$H_1=\frac{\omega_1 d}{2\left(1+t_1{}^2\right)^{1/2}}\left\{t_1+\left[4\left(\frac{T_A}{\omega_1 d}-\frac{y}{d}\right)^2-1\right]^{1/2}\right\} . \tag{21}$$

Therefore, the magnitudes of main line tension and its components follow directly from the equations

$$H_3=H_2-H_1 \tag{22}$$

for the standing skyline,

$$H_3=2H_2-H_1 \tag{23}$$

for the running skyline, and

$$V_3{}^c=H_3t_1-1/2R_3 \tag{24}$$

and

$$T_3{}^c=\left(\left(V_3{}^c\right)^2+\left(H_3\right)^2\right)^{1/2} \text{ for both.} \tag{25}$$

The tension at the left anchor can be determined with the catenary relationship

$$T_3{}^a=T_3{}^c+\omega_1 y. \tag{26}$$

Error

As noted earlier, the analysis presented here yields accurate results for taut lines only. In the running skyline configuration, this assumption is nearly always satisfied since the tension of the haulback line provides enough force on the carriage to maintain tension in the main line, even for a no-load condition. The same is not true for the standing skyline. Conditions can arise where the tension requirement for the main line is so small that considerable sag will develop. In this section, we examine the error that is induced from low tension in the main line of the standing skyline.

An accurate analysis of the main line, shown in figure 5, would consider the catenary shape it adopts between the left anchor and the carriage. The shape would depend on the horizontal force, H_3, required to hold the carriage in position and would influence the vertical force lifting the carriage, V_3. Such an analysis would yield a relationship between these forces, namely,

$$\left. V_3 \right)_{catenary} = \frac{\omega_3}{2} \left(y \coth \frac{\omega_3 d}{2H_3} - \bar{s} \right); \tag{27}$$

where

$$\bar{s} = \left\{ y^2 + \left(\frac{2H_3}{\omega_3} \sinh \frac{\omega_3 d}{2H_3} \right)^2 \right\}^{1/2}.$$

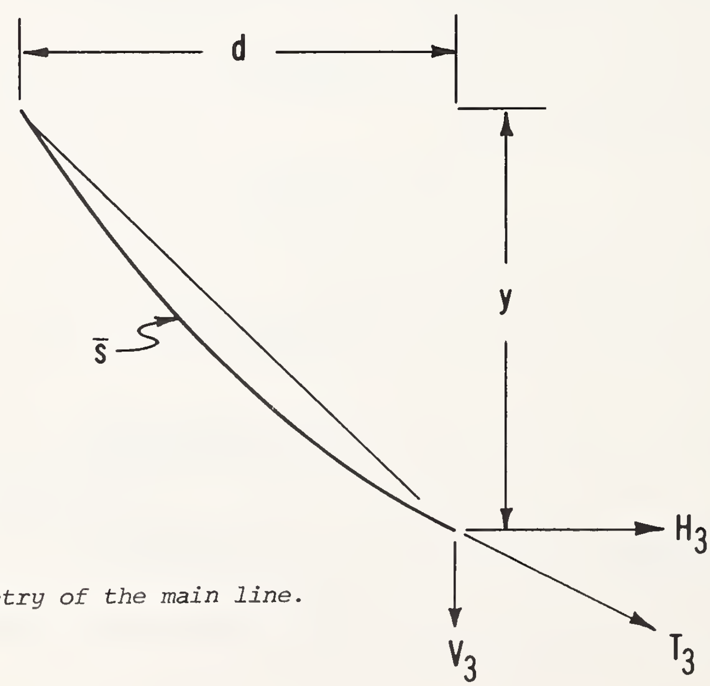

Figure 5.--Geometry of the main line.

By comparison, the approximate analysis developed in this paper yields the relationship

$$V_3 = H_3 \frac{y}{d} - \frac{\omega_3}{2}\left(y^2+d^2\right)^{1/2} . \tag{28}$$

The difference arises from the assumptions made in equations (4), (5), (6), (7), and (8), which ignore the sag of the main line as would be described by the catenary and as would actually exist. It should be apparent that the magnitude of sag, and thus the discrepancy between $\left.V_3\right)_{catenary}$ and V_3 that is introduced, is a function of the tautness of the main line, which is in turn a function of the horizontal component of tension, H_3. More specifically, one can recognize that for fixed geometry and line weight per unit length, more sag and thus more discrepancy are caused by lower values of H_3. This can be summarized as an error defined as

$$\text{ERROR} = \frac{\left.{}^{V_3}/_{\omega_3 d}\right)_{catenary} - {}^{V_3}/_{\omega_3 d}}{{}^{H_3}/_{\omega_3 d}} . \tag{29}$$

This expresses the discrepancy between the approximation for V_3 and that derived from a catenary analysis as a percentage of the horizontal tension required in the main line. All terms have been normalized by the product $\omega_3 d$ to reduce the error to a function of the ratios $\left({}^{y}/_{d},\ {}^{H_3}/_{\omega_3 d}\right)$ only. A plot of the variation is presented in figure 6.

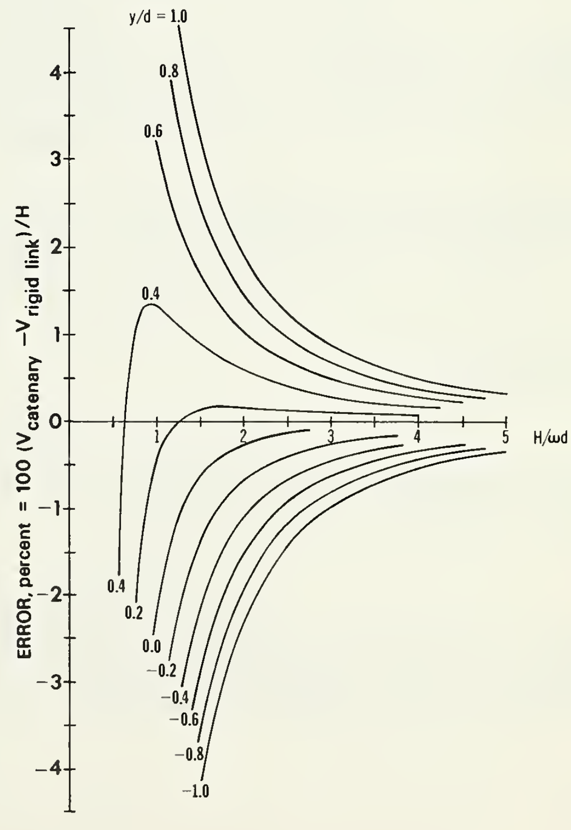

Figure 6.--Error in main line force due to approximate solution.

Therefore, figure 6 provides, for a given carriage location (i.e., y/d), given line weight and horizontal tension requirement (i.e., $H_3/\omega_3 d$), a measure of the error introduced by the approximate analysis presented. Notice that until the ratio $H_3/\omega_3 d$ approaches 2.0, the error for all physically realistic geometries is negligible.

Numerical Example

The computational procedure suggested for a hand-held or small desk-top computer is described best by a numerical example. For the example presented here, we chose a standing skyline anchored with the values

L = 2,000 feet (609.6 meters),

h = 1,000 feet (304.8 meters),

d = 1,400 feet (426.7 meters),

y = 850 feet (259.1 meters),

ω_1 = 2.89 pounds/foot (42.18 newtons/meter),

ω_3 = 1.85 pounds/foot (27 newtons/meter),

and T_A = 53,300 pounds (237 090 newtons).

The first step might be a determination of the cable weights involved in the configuration. As indicated in equations (4), (5), and (6), the summation of these weights can be estimated as

$$\left(R_1+R_2+R_3\right) = 9{,}551 \text{ pounds (42 485 newtons).}$$

Equation (9) provides a direct computation of line segment 2, horizontal tension component, as

$$H_2 = 49{,}108.0 \text{ pounds (218 443 newtons).}$$

The computations are completed by substituting into the payload equation (19) which for the standing skyline gives

$$W_G = 12{,}763.2 \text{ pounds (56 774 newtons).}$$

To assess the error which is introduced, the computations are continued, to determine

$$H_3 = 4{,}632.1 \text{ pounds (20 605 newtons)}$$

as the horizontal tension required to hold the carriage at d = 1,400 feet (426.7 meters). This implies that

$$\left(\frac{y}{d}\,,\ \frac{H_3}{\omega_3 d}\right) = (0.607,\ 1.788)$$

which, from figure 6, indicates an error of 1.26 percent. Therefore, a catenary analysis would have altered the load-carrying capability by approximately 58 pounds (258 newtons).

The procedure for determination of a running skyline load capability would be the same except for the variations in the equations which have been noted under "Gross Payload."

Literature Cited

1. Carson, Ward W.
   1975. Programs for skyline planning. USDA For. Serv. Gen. Tech. Rep. PNW-31, 40 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

2. Carson, Ward W., and Charles N. Mann.
   1970. A technique for the solution of skyline catenary equations. USDA For. Serv. Res. Pap. PNW-110, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

3. Carson, Ward W., and Charles N. Mann.
   1971. An analysis of running skyline load path. USDA For. Serv. Res. Pap. PNW-120, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

4. Carson, Ward W., and Donald D. Studier.
   1973. A computer program for determining the load-carrying capability of the running skyline. USDA For. Serv. Res. Pap. PNW-157, 26 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

5. Carson, Ward W., Donald D. Studier, and Hilton H. Lysons.
   1971. Running skyline design with a desk-top computer plotter. USDA For. Serv. Res. Note PNW-153, 21 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

6. Lysons, Hilton H., and Charles N. Mann.
   1967. Skyline tension and deflection handbook. USDA For. Serv. Res. Pap. PNW-39, 41 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

7. Mann, Charles N.
   1969. Mechanics of running skylines. USDA For. Serv. Res. Pap. PNW-75, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

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